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PRELIMINARY EVALUATION OF ATS-6/~~GOES~~GEOS-3 SATELLITE-TO-SATELLITE TRACKING DATA

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1.0 Introduction

Data relay via a synchronous space station for military and public usage has demonstrated many times over the practicability of eliminating multiple ground based, line-of-sight data relay links serving the same purpose as the single satellite relay station. Point-to-point communications between suitably equipped ground stations through a synchronous relay station is an everyday occurrence. Various experiments with aircraft and ships equipped with the necessary systems, have illustrated the feasibility of communication and navigation via a synchronous satellite data relay station. The apparent extension of this experience is the provision for one termination of the data relay link to be a highly mobile station, a scientific, unmanned satellite in near earth orbit. Under these conditions, ground station radio visibility of the near earth satellite through the synchronous relay satellite exists over long time periods of the near earth orbit, a most desirable situation for those responsible for tracking, telemetry, command, and control of the near earth satellite.

2.0 Measurement Description

The first data relay satellite capable of supporting tracking data acquisition from low altitude, earth orbiting satellites is the Applications Technology Satellite ATS-6, launched May 30, 1974. ATS-6 features such as

the 30 foot diameter paraboloidal antenna, (43 db gain, 1^{o} BW, 650 km diameter illumination on earth*), the 20 watt transmit capability at UHF, and the 40 MHz relay bandwidth capability permit a tracking data relay experiment with the Geodetic Earth Orbiting Satellite, GEOS-3, launched April 9, 1975. The figure shown here is taken from the GEOS-C Mission Plan, May 1974. By contrast the GEOS-3 spacecraft has a 1.5 watt transmit capability and a maximum antenna gain of 6 db. This contrast emphasizes that the ATS-6 satellite is truly a space station which replaces many ground based stations. However, the ATS-6 space station must have a single cooperative ground station, and in our discussion and results that ground station was Rosman, North Carolina, a ground station in the Goddard Spacecraft Tracking and Data Network.

In the experiment, two measurements were made and they are described as:

- the time interval from the origination of a time indexed phase mark on a transmission from the Rosman ground station to the time of reception of that phase mark at the Rosman ground station. The travel of the transmission is to the ATS-6 space station, to the GEOS-3 satellite, a return to ATS-6, and the final relay back to the Rosman ground station. The time of travel is roughly 1/2 second and this measurement is called the range sum measurement.
- the time interval required to accumulate a prechosen and known phase change of the received signal at the Rosman ground station relative to the Rosman signal transmission. This

* 20 positions across earth diameter + GEOS ALT.

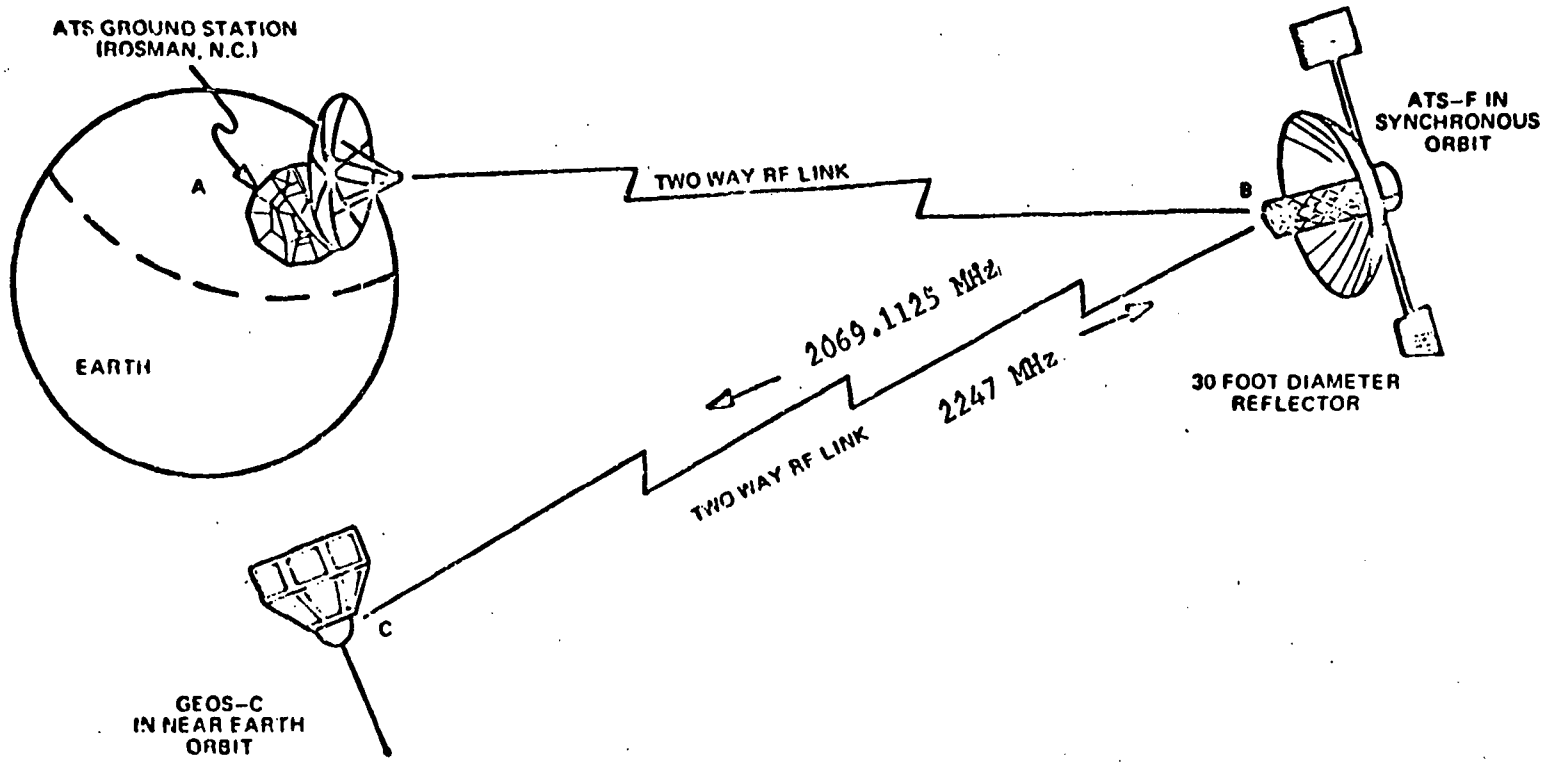

Figure 1. Satellite-to-Satellite Tracking Relay Experiment.

measurement is called average range rate sum measurement. Recently the measurement has been modified to be the phase change of the received signal over a prechosen and known time interval. The modified and original measurements are essentially the same, and both require coherence throughout the radio frequency link.

3.0 GEOS-3 and ATS-6 Reference Orbits

The evaluation of the ATS-6/GEOS-3 tracking relay experiment depends upon direct ground tracking of the target spacecraft and the relay spacecraft. Without direct ground tracking of the target and relay spacecrafts, those trajectories determined from data relay tracking alone are subject to the valid criticism of nonexistent verification through independent ground based measurements. Reference orbits must be determined from direct ground tracking to evaluate the potential of data relay tracking, and these reference orbits must be sufficiently accurate to make a meaningful appraisement.

GEOS-3, the target spacecraft, has an altitude of 840 kilometers, an eccentricity of .0014 and an inclination of 115 degrees. GEOS-3 carries a VHF beacon suitable for ground based angle tracking by Minitrack; and for the data span investigated here the next figure shows the observed minus computed values from the orbit determination process for the period May 2, 1975 through May 5, 1975.

Measurements made with range and range rate type ground systems for the ATS-6 satellite result in observed minus computed values in the orbit determination process on the order of several meters, and these differences

NUMBER OF SITES TRACKING: 7

NUMBER OF ANTENNA FIELDS: 13

DATA PERIOD: MAY 2, 1975 THROUGH MAY 5, 1975

EAST DIRECTION COSINE DATA POINTS IN SOLUTION: 74 (1 EDITED)

NORTH DIRECTION COSINE DATA POINTS IN SOLUTION: 75 (3 EDITED)

EAST DIRECTION ANGLE ERROR IN RADIANS: $-.33\ (10^{-4})$ MEAN

$.12\ (10^{-3})$ STANDARD DEVIATION

NORTH DIRECTION ANGLE ERROR IN RADIANS: $.19\ (10^{-3})$ MEAN

$.27\ (10^{-3})$ STANDARD DEVIATION

EAST DIRECTION EQUIVALENT ERROR IN METERS: 30 MEAN

120 STANDARD DEVIATION

NORTH DIRECTION EQUIVALENT ERROR IN METERS: -190 MEAN

270 STANDARD DEVIATION

Figure 2. GEOS-3 Minitrack Reference Orbit.

between observations and the calculated orbit appear non-random. Statistics on the differences are shown in the next figure. The type of ATS-6 transponder used in the accumulation of the ATS reference orbit range and range rate data can be a phase locked transponder or a non-phase locked transponder but the minimum tracking error available for range can be shown to be independent of the transponder type. At this point we have two reference orbits that appear to be very accurate in terms of the O-C value, and these orbits determined from ground measurements of range, range rate, and angle will serve as the reference against which data relay tracking will be compared.

Errors in the reference orbit are sensitive to amounts of tracking data taken, the biases and noises of the measurements, and the timing of the data taking. For the most accurate reference orbits, it would be necessary to have continuous ground tracking of the target and relay spacecraft from as many simultaneous viewing ground stations as possible. Since this is not practical, the forced compromise is made of maximum station viewing (data taking time) from stations randomly distributed along the satellite ground track. For GEOS-3, this condition is met relatively well. For ATS-6, two stations, both in the northern hemisphere, take data over less than one orbit. For the synchronous satellite ATS-6, the range data primarily determines the orbit; the range rate data has little effect upon the solution. In addition, the reference orbit for ATS-6 depends upon data also used for the satellite-to-satellite orbits, and there is not complete independence as in the Minitrack GEOS-3 orbit. This is evident in the next viewgraph which shows the data spans used for this satellite-to-satellite orbit determination.

NUMBER OF SITES TRACKING: 2

DATA PERIOD: MAY 4, 1975 07:00 TO MAY 4, 1975 23:00

RANGE DATA POINTS: 29 (0 EDITED)

RANGE RATE DATA POINTS: 29 (0 EDITED)

RANGE O-C'S IN METERS: -.015 MEAN
1.7 STANDARD DEVIATION

RANGE RATE O-C'S IN METERS/SECOND: -.0025 MEAN
.0072 STANDARD DEVIATION

Figure 3. ATS-6 and Range Rate Reference Orbit.

DIRECT TRACK OF ATS-6: 5.4.74 07:10:39
TO 5.4.74 23:02:27

SST TRACK:

- 5.3.74, 21:06:30 TO 22:08:20
- 5.3.74, 22:45:10 TO 23:46:40
- 5.4.74, 08:34:40 TO 09:13:00

Figure 4. Data Spans for SST.

4.0 Reference Orbit Comparisons

The next 7 figures present results of satellite-to-satellite orbit determination and the comparison with the reference orbits. The table of information about the observed minus computed values describes very small differences between the actual observations and the computed observations from the converged solutions for the two orbits. Thirteen elements were estimated in the solution and there were no constraints placed upon the 13 elements:

- o position of GEOS-3 at epoch
- o velocity of GEOS-3 at epoch
- o position of ATS-6 at epoch
- o velocity of ATS-6 at epoch
- o solar radiation pressure parameter

The next 6 figures present an ephemeris comparison between the GEOS-3 reference orbit and the SST determined orbit. Note that the cross track difference between the reference and the SST orbit is large for GEOS-3. Although it is not shown here, the cross track difference between the ATS-6 reference orbit and the SST ATS-6 orbit is similarly hundreds of meters and is the significant error in position for ATS-6.

NUMBER OF SITES TRACKING FOR SST: 1

NUMBER OF SITES TRACKING FOR ATS-6: 2

DIRECT RANGE DATA POINTS: 439 (9 EDITED)

DIRECT RANGE RATE POINTS: 349 (99 EDITED)

RANGE SUM DATA POINTS: 282 (194 EDITED)

DIRECT RANGE O-C 'S IN METERS: .0021 MEAN
.93 STANDARD DEVIATION

DIRECT RANGE RATE O-C'S IN METERS/SECOND: .0028 MEAN
.024 STANDARD DEVIATION

RANGE SUM O-C'S IN METERS: .0089 MEAN
9.2 STANDARD DEVIATION

Figure 5. Satellite-to-Satellite Tracking
Orbits ATS-6 and GEOS-3.

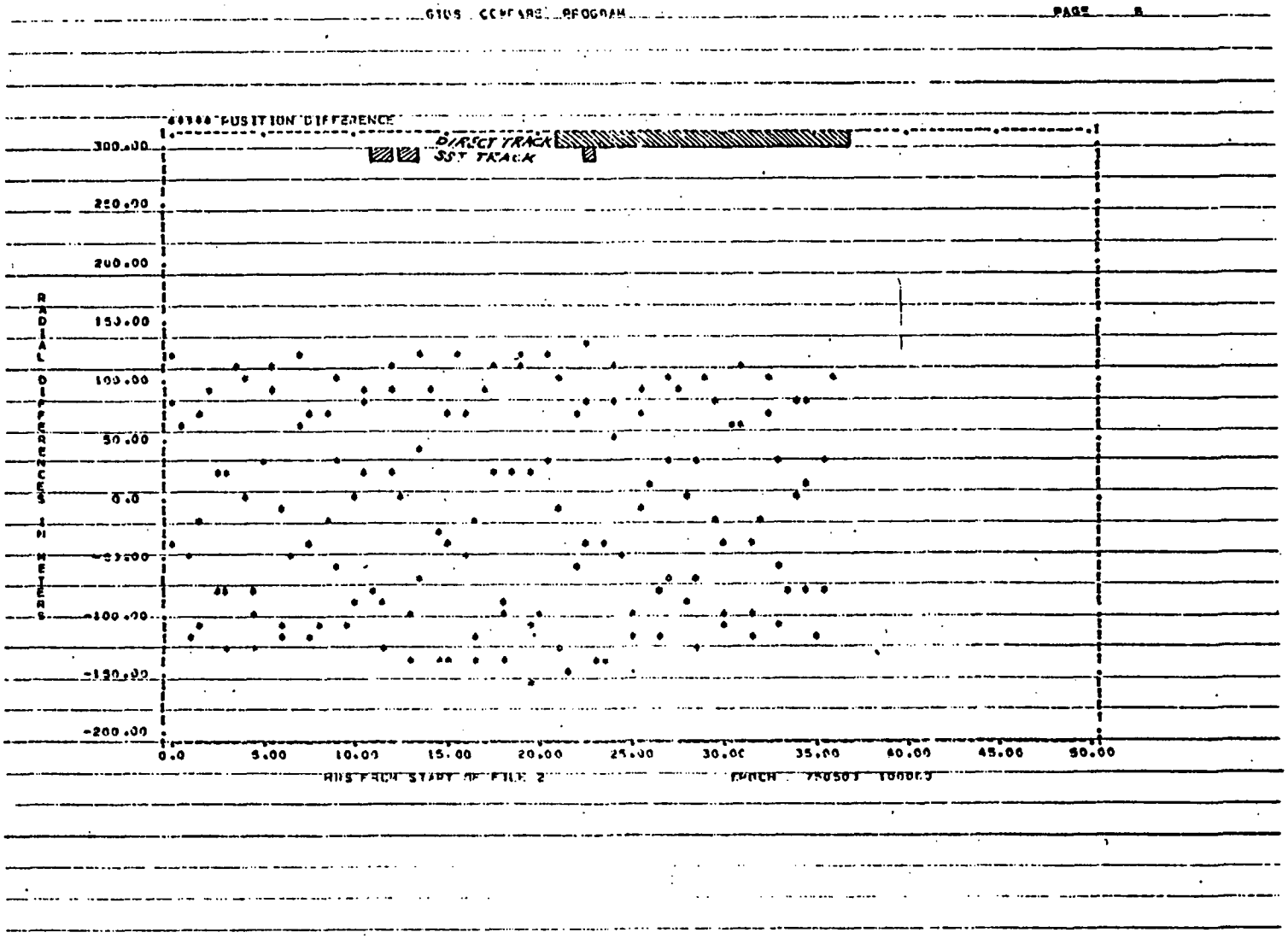

Figure 6. GTDS Compare Program (Radial Differences in Meters).

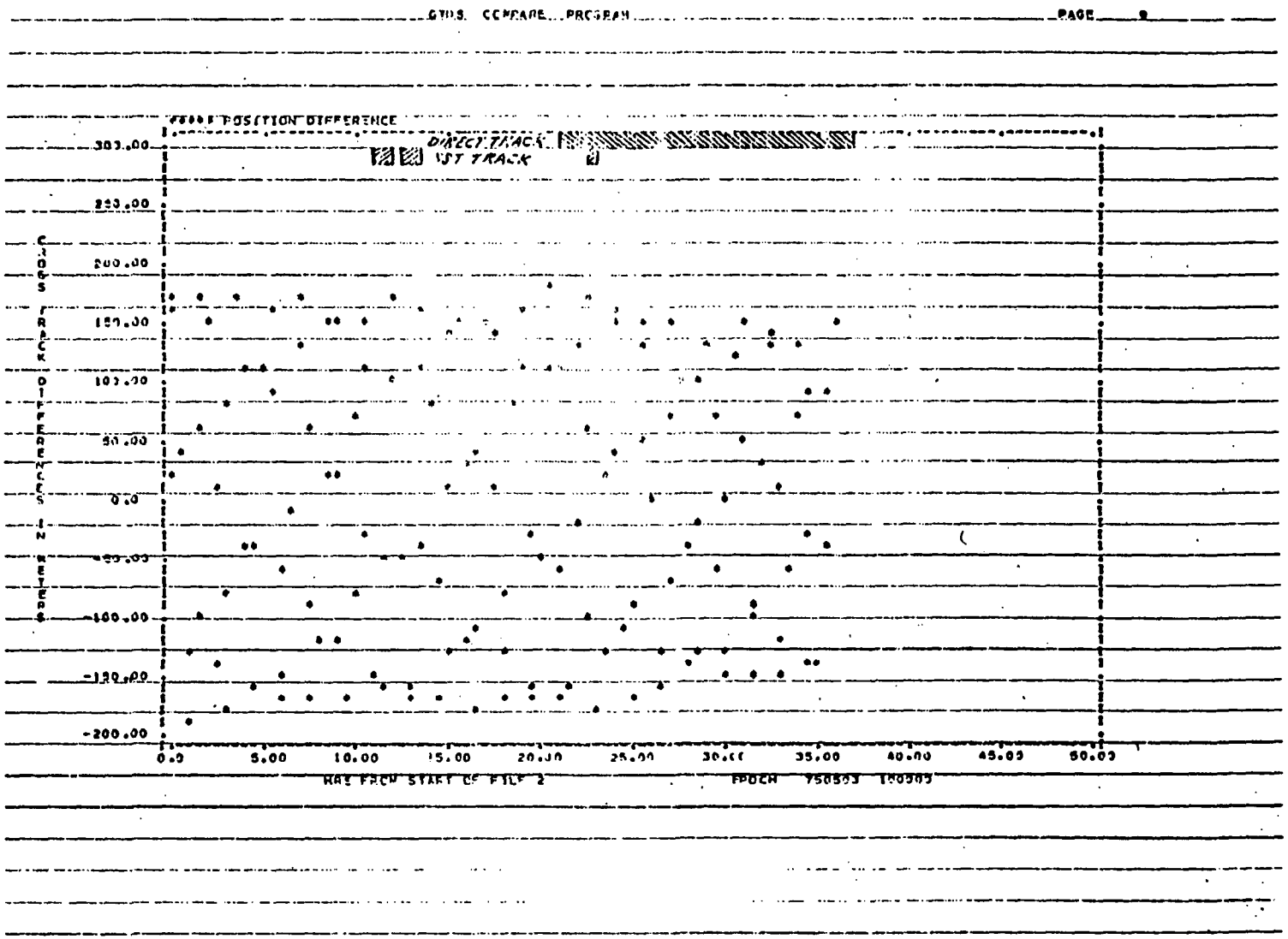

Figure 7. GTDS Compare Program (Cross Track Differences in Meters).

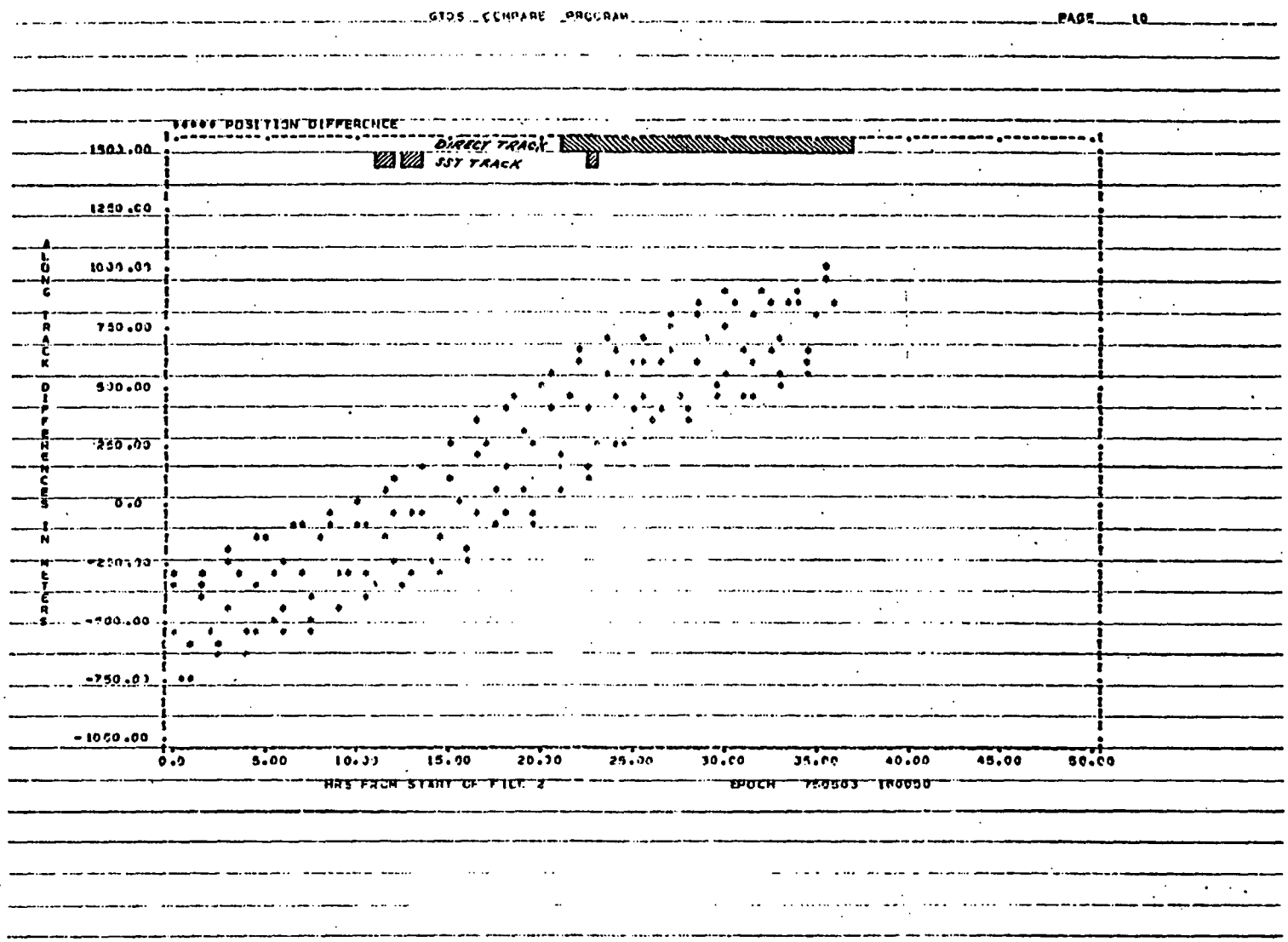

Figure 8. GTDS Compare Program (Along Track Differences in Meters).

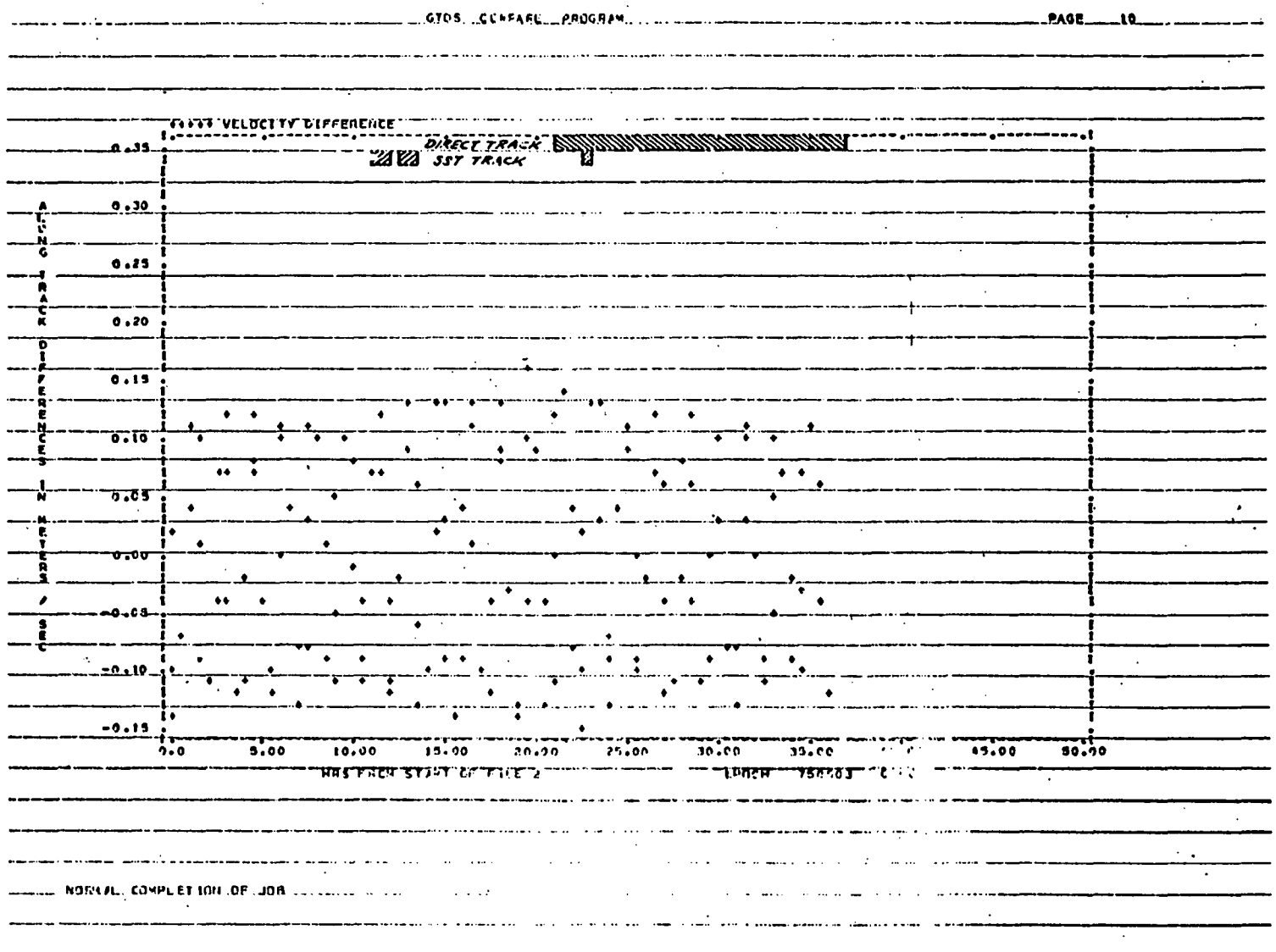

Figure 9. GTDS Comparison of Direct Track Differences in Meters/Sec).

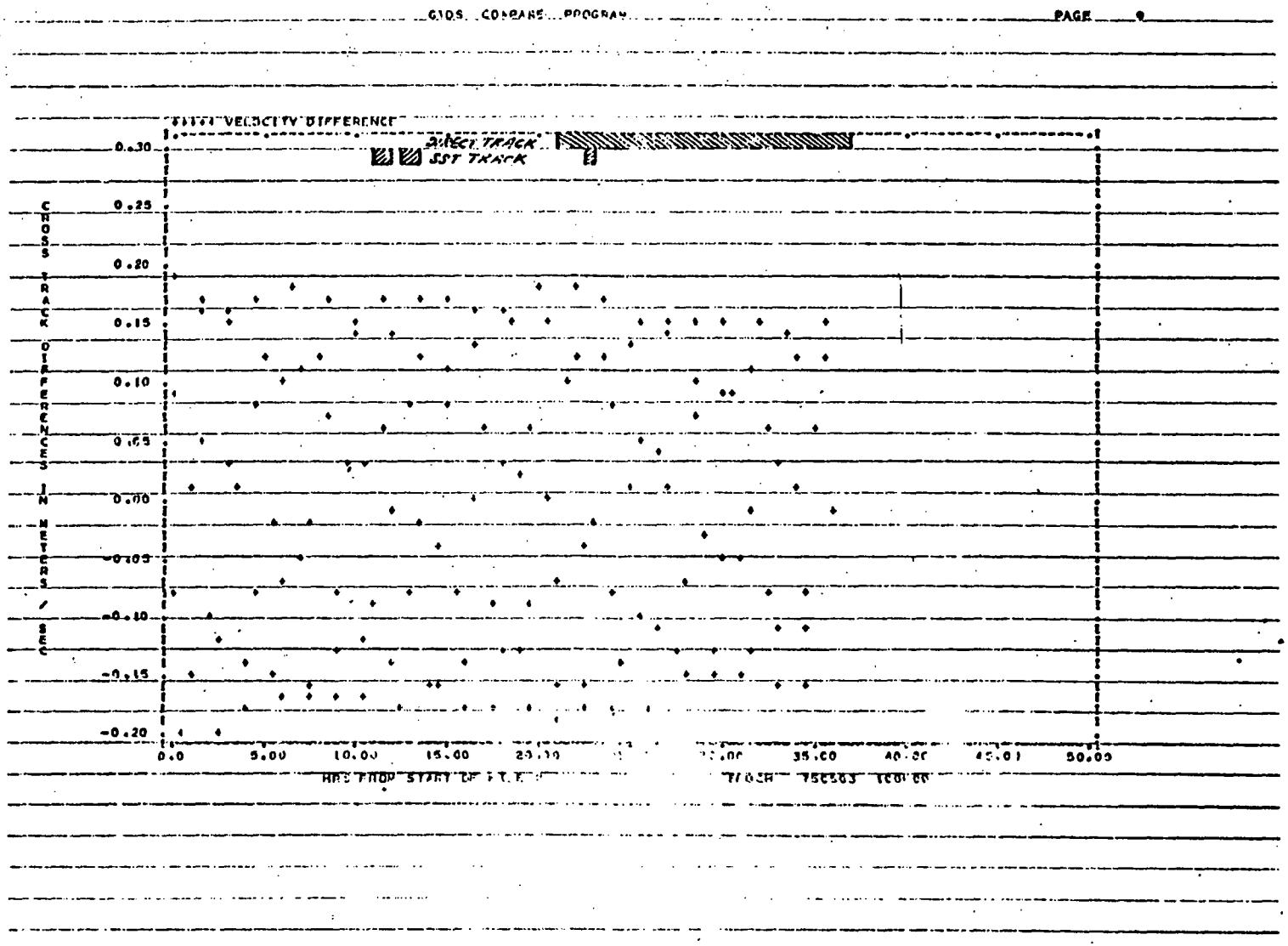

Figure 10. GTDS Compare Program (Cross Track Differences in Meter/Sec).

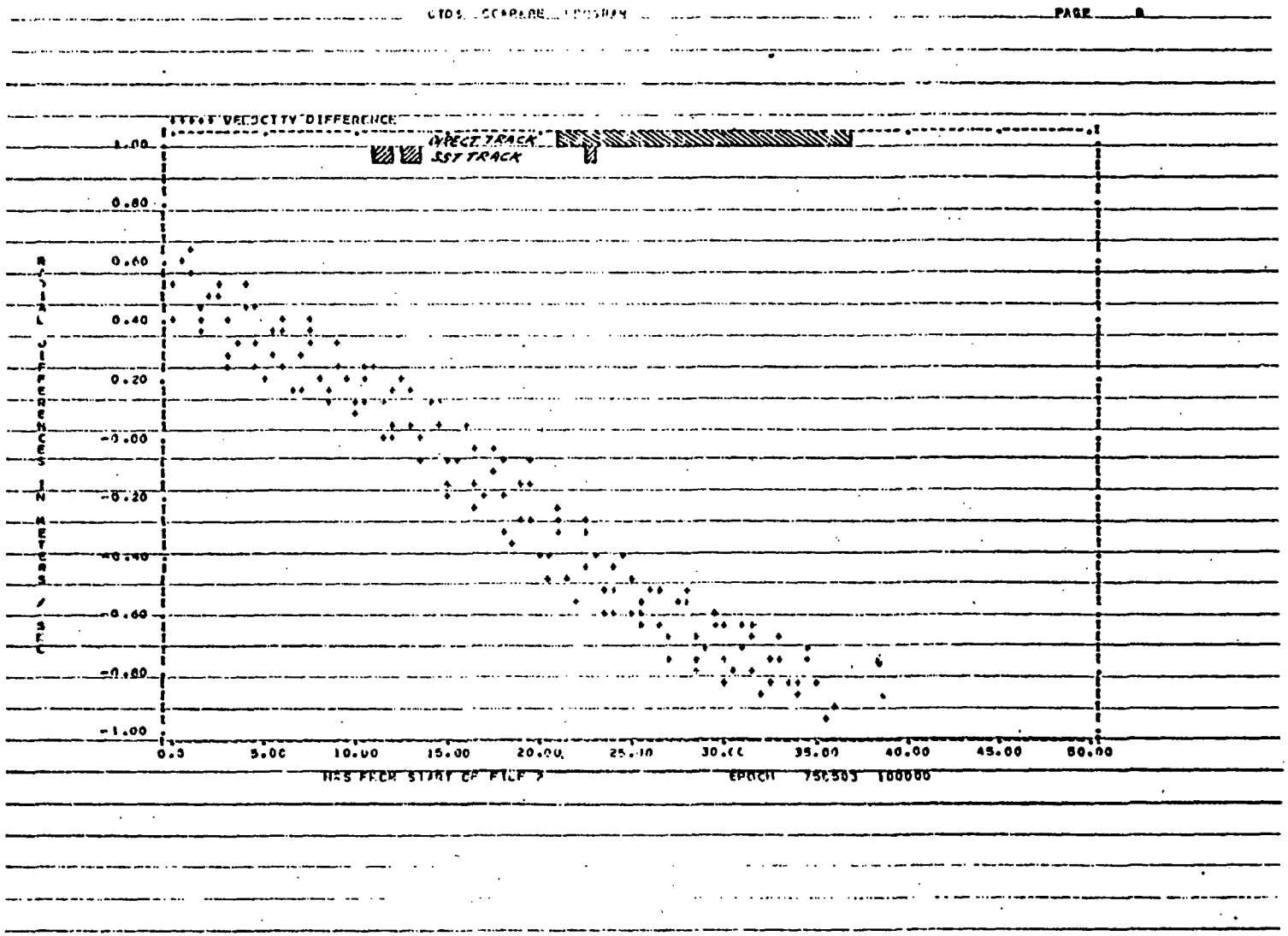

Figure 11. GTDS Compare Program (Radial Differences in Meters/Sec).

5.0 Conclusions

There is considerable work to be done in evaluating the satellite-to-satellite tracking experiment. The novelty of the technique will force a learning period just as Goddard experienced with all of its tracking systems as they were introduced into the orbit determination system process. From my point of view, this experiment is to point out the difficulties and the pitfalls of determining orbits via a synchronous satellite relay. From this very preliminary evaluation, the experiment has met my expectations.